# Statewide Water Supply Initiative Update
# Technical Memorandum

Prepared for: Colorado Water Conservation Board
Project Title: SWSI Update

Subject: Scenario Planning and Gap Analysis Methodologies
Date: November 1, 2017 DRAFT
To: Colorado Water Conservation Board
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# Section 1: Methodology Objectives

This Technical Memorandum (TM) describes the scenario planning and gap analysis technical framework and methodology used for the Statewide Water Supply Initiative (SWSI) Update. The key objectives of the scenario planning and gap analysis methodology are the identification of quantifiable parameters that can be used in evaluating water supply and water demand conditions. This TM includes the following major components:

- Identify how the SWSI Update will build upon and improve recent past Colorado Water Conservation Board (CWCB) water planning efforts including:
  - SWSI 2010
  - 2011 – 2015 Basin Implementation Plans
  - 2015 Colorado's Water Plan
- Outline an overarching planning methodology framework that will be consistently utilized across all aspects of this SWSI Update including water supply availability, municipal and industrial demand projections, agricultural demand projections, and environmental and recreation flow assessments.
- Define the specific approach to quantifying supply versus demand gaps.

This SWSI Update will not evaluate identified projects and processes (IPPs) or update existing Basin Implementation Plans. Instead, the SWSI Update will quantify supply versus demand gaps by evaluating how existing water management strategies and existing water infrastructure might meet future water needs evaluated for unique planning scenarios. The updated range of gaps developed by planning scenario for each river basin and associated analysis tools and data sets will be provided to the basins and will serve as a starting point for subsequent basin-directed Basin Implementation Plan (BIP) updates. This approach allows gaps to be calculated using consistent methods across all basins while allowing each basin to be the lead author of their updated Basin Implementation Plans. The overall SWSI Update process, including pre-and post-SWSI Update phases, is detailed in Figure 1.

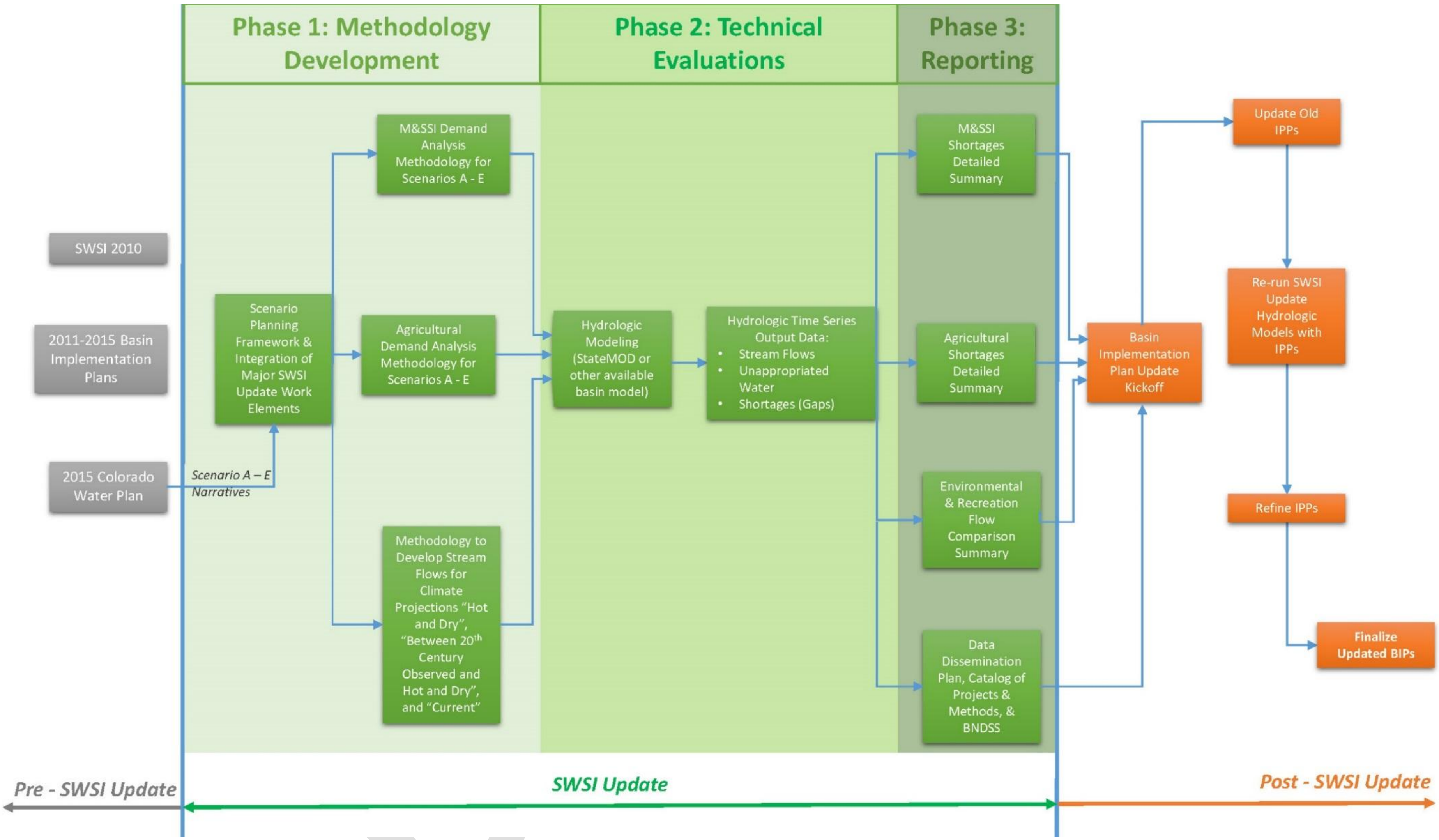


Figure 1: SWSI Update Process

# Section 2: Background on Previous Methodologies

## 2.1 Overview of Methodologies Used in SWSI 2010

SWSI 2010 was the State's previous effort of establishing a technical evaluation of Colorado's water needs and future gaps. SWSI 2010 was a collaborative effort between the State, Basin Roundtables, and the public. The analysis looked at basin-level nonconsumptive needs, municipal and self-supplied industrial (M&SSI) needs, agricultural needs, and an analysis of water availability. Additionally, SWSI 2010 provided a high-level look at potential IPPs to solve the consumptive and nonconsumptive needs gap. The following sections provide an overview of key methodologies used in SWSI 2010, as well as identification of limitations in the previous methodologies.

### 2.1.1 Population Projection and M&SSI Gap Analysis Approach

SWSI 2010 did not establish a true scenario planning framework that spanned across all aspects of the technical evaluation work. However, efforts were made to include possible future variability in projected populations. SWSI 2010 included low, medium, and high 2050 population projections that were calculated by varying and extending the State Demographer's Office (SDO) current population projection assumptions. These projections fed into the development of three 2050 baseline municipal water demands that were calculated by multiplying historical per capita water use by the projected 2050 population projections. Low, medium, and high self-supplied industrial forecasts were developed for energy and thermoelectric demands, while a single 2050 demand was developed for large industry and snowmaking demands.

As part of the SWSI 2010 gap analysis method, basins collaboratively tabulated identified projects and processes (IPPs) to improve water supplies within their respective basin. Specifically, IPPs were defined as anticipated yield from the following:

- Agricultural Transfers
- Reuse
- Growth into Existing Supplies
- Regional In-Basin Projects
- New Transbasin Projects
- Firming In-Basin Water Rights
- Firming Transbasin Water Rights

Additionally, ranges of passive and active municipal water conservation opportunities were estimated. With these demands and IPPs, the overall M&SSI 2050 Gap was calculated as follows:

$$2050\ M\&SSI\ Gap\ = [2050\ Baseline\ Water\ Demands] - [High\ Passive\ Conservation] - [Current\ M\&SSI\ Supply] - [2050\ IPPs]$$ [1]

A range of 2050 M&SSI gaps were calculated by using high and low baseline water demands combined with higher and lower assumptions regarding the success rate of IPPs.

### 2.1.2 Agricultural Gap Analysis Approach

Agricultural demands were calculated by multiplying estimated different ranges of future irrigated acreage by the minimum of either Irrigation Water Requirement (IWR) or the Water Supply Limited Crop Consumptive Use (WSL CU). These terms are defined below:

[1]SWSI 2010 M&I demand forecasts did not include potential decreases in demand due to active conservation programs. Active conservation was, however, considered a potential strategy for meeting the M&I gap.

- Crop Consumptive Use (CU) is calculated by a software package (StateCU) that uses the modified Blaney-Criddle method and calculates the amount of water needed at the plant considering crop evapotranspiration (ET) for basin specific climate conditions, natural precipitation and soil evaporation, and other localized losses.
- Irrigation Water Requirement (IWR) is the amount of water that must be applied to the crop to meet the full crop consumptive use.
- Water Supply Limited Crop Consumptive Use (WSL CU) is the amount of applied water consumed by the crop based on the available applied water from rivers, groundwater, or reservoirs. Precipitation consumed by crops is not included in applied water, but rather is part of the CU calculation.

Agricultural gaps were defined as the difference between the IWR and WSL CU. In SWSI 2010, this difference was termed as a "shortage" rather than a "gap." Importantly, the above calculations did not consider how crop irrigation demand translates to actual required headgate diversions. Low and high future irrigated acreages were estimated by taking current irrigated acreage and assuming different reductions in those acreages. Reductions in irrigated acreage were based on a key assumption that agricultural to municipal water transfers would meet a portion of future M&SSI gaps, and therefore scenarios with higher M&SSI gaps had higher reductions in irrigated acreage.

### 2.1.3 Environmental & Recreation Focus Area Mapping

SWSI 2010 developed a methodology to map environmental and recreation focus areas within each basin. The Basin Roundtables within the Arkansas, Colorado, and Yampa-White Basins utilized State Water Supply Reserve Account (WSRA) funding to conduct further studies to quantify environmental and recreation flow needs.

SWSI 2010 environmental and recreation focus area mapping included detailed subcategorization that highlighted the key environmental and recreation attributes in the focus areas. However, explicit environmental and recreation flow needs were not quantified in SWSI 2010. Instead, the detailed focus area mapping and key attribute categorization information was intended to assist the basin roundtables in addressing the following key questions:

- Are there existing protections/efforts for environmental and recreation focus areas?
- Are there areas without protections that need further study?
- What strategies are needed to support priority areas?
- Are there areas where new flow or water level quantification is appropriate?
- Are there areas where a project, whether structural (e.g., river restoration) or nonstructural, can be identified and implemented?
- Are there areas where no action is needed at the current time?

### 2.1.4 SWSI 2010 Approach Limitations

The approaches described in the previous sections provided for a range of 2050 M&SSI gaps for each basin and a range of irrigated agricultural acres for each basin. However, agricultural gaps were not explicitly calculated, and M&SSI gaps had certain embedded assumptions regarding varying future conservation success rates and varying success rates of future potential IPPs. The analyses considered a mix of low, medium and high demand assumptions and varying IPP success rates, with these varying assumptions generally being described as "scenarios". This approach in SWSI 2010 was helpful in beginning to consider uncertainties regarding the future, and the framework of a more formal scenario planning approach designed to more deliberately consider future uncertainties was subsequently developed in the 2015 Colorado's Water Plan. The benefits of the use of a more formal scenario planning process are described in further detail in Section 2.3.

In addition to the nascent scenario planning approach, SWSI 2010 had additional key analysis limitations, summarized below:

- Potential impacts of climate change were not considered in SWSI 2010's M&SSI or agricultural demands analysis methodology.
- M&SSI gap quantification was presented at the basin scale and did not explicitly consider hydrologic analyses that could tie the gaps to select representative spatial locations.
- Agricultural demands did not consider how crop demands translate to headgate demands.
- Existing water supplies were generally assumed to be fully reliable without hydrologic analysis to assess potential vulnerabilities.
- Hydrologic analysis tools that would allow for evaluation of varying hydrology and the cumulative impacts and competition for water associated with future IPPs were not used in SWSI 2010.
- Hydrologic analysis of various supply and demand conditions were not performed and therefore potential flow changes in environmental and recreation focus areas could not be presented.

## 2.2 2011-2015 Basin Implementation Plans Overview

After SWSI 2010, Basin Implementation Plans (BIPs) were developed for each of the river-basins within Colorado. These plans generally included the following components:

- Basin goals and measurable outcomes
- Consumptive and non-consumptive needs evaluation
- Projects and methods
- Implementation strategies for the projects and methods
- Summary of how the plan will meet goals and measurable outcomes

The consumptive and non-consumptive needs developed in the BIPs were largely based on SWSI 2010 analyses and updated and refined as required. The identified projects and methods developed in the BIPs effectively produced an updated and enhanced list of IPPs from those developed in SWSI 2010. The key components and concepts of each of the BIPs were then incorporated into the 2015 Colorado's Water Plan.

The current SWSI Update will incorporate further enhancements into how the supply versus demand gaps are calculated. Post-SWSI Update work is anticipated to follow the process described below:

1. The SWSI Update will estimate gaps for each of the five planning scenarios;
2. The analysis tools will be provided to the BRTs;
3. BRTs will be able to use the tools to evaluate IPPs and projects and methods to meet their future water needs;
4. The BRTs will update their BIPs and will be able to use the SWSI tools for their analyses.

## 2.3 2015 Colorado's Water Plan Overview

The 2015 Colorado's Water Plan (CWP) built upon and updated past work developed in SWSI 2010 and the Basin Implementation Plans. Two key aspects of the plan were the adoption of a formal scenario planning process to identify the full range of uncertainties facing Colorado in regards to water sustainability, and a partial summary of BIP Municipal, Industrial, and Agricultural Infrastructure Projects and Methods.

As described in Section 6.1 of the CWP, the CWCB has adopted a formal scenario planning approach that has been used by many major water providers across the West. The formal scenario planning method varies from the traditional use of high, medium, and low conditions (used in SWSI 2010) by acknowledging that the future may have greater degrees of uncertainty than can be captured with the previously used high, medium and low methods.

The overall formal scenario planning method includes the following general steps:

1. Develop expansive list of drivers that can influence future water planning conditions (previously conducted by IBCC and documented in CWP).
2. Identify most uncertain and most important key drivers (previously conducted by the IBCC and documented in the CWP)
3. Develop scenario narratives that define distinctly different plausible futures that warrant planning (previously conducted by the IBCC and documented in the CWP)
4. Quantify future supply and demand conditions for each scenario per identified drivers (part of SWSI Update)
5. Calculate baseline supply versus demand gaps for each scenario without considering future projects or processes that may be able to address the calculated gap (part of SWSI Update)
6. Develop portfolios of projects and processes that can be used to address gaps for each planning future (to be completed by BRTs as part of future, post-SWSI Update efforts)

This SWSI Update will use the scenarios previously developed and defined as part of the 2015 CWP as a foundational element for updating the supply and demand gap analysis. The five scenarios are shown graphically in Figure 2, while drivers of change and resulting implications are depicted in Figure 3. The five planning scenarios are defined in narrative format for the year 2050 in Table 1:

Figure 2: Graphical Depiction of Planning Scenarios

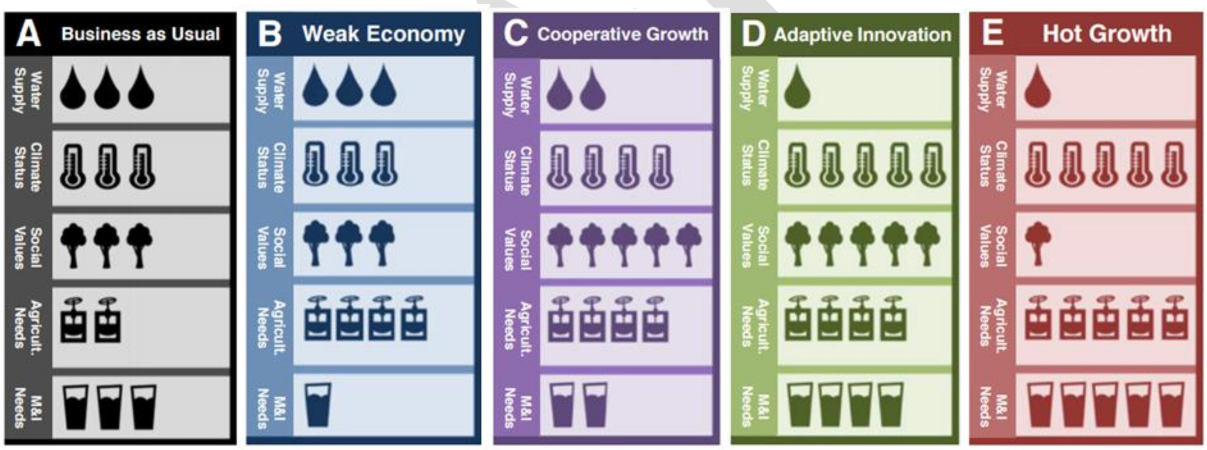

Table 1: Planning Scenario Drivers Implications & Graphical Summary

| Drivers of Change | Assumption Category | Business as Usual | Weak Economy | Cooperative Growth | Adaptive Innovation | Hot Growth |
|---|---|---|---|---|---|---|
| Economy | Assumed Conditions | Similar economic growth to past | Lower economic growth than past | Similar economic growth to past | Slightly higher economic growth than past | High economic growth |
| | Population Implications | ~ No adjustment from SDO forecast | - Lower population growth throughout state. | ~ Similar to SDO forecast, higher growth in mtn. resort & urban areas | + High population growth, focused on urban areas | + Higher population growth |
| Agricultural Status | Assumed Conditions | Greater decrease in irrigated land due to urbanization, ag less able to compete with urban areas for water | Lesser decrease in irrigated land due to urbanization, ag less able to compete with urban areas for water | Decrease in irrigated land due to urbanization, ag better able to compete with urban areas for water | Decrease in irrigated land due to urbanization, ag better able to compete with urban areas for water | Much greater decrease in irrigated land due to urbanization, ag better able to compete with urban areas for water |
| | Ag. Demand Implications | + + Ag. demands higher | - Ag. demands slightly lower | + Ag. demands slightly higher | + + Ag. demands slightly higher | + + + Ag. demands much higher |
| Energy Water Needs | Assumed Conditions | Similar to current conditions, no oil shale | Weak economy limits energy development | Increased energy conservation | Renewable & clean energy dominates | Fossil fuel energy dominates |
| | Energy Demand Implications | Moderate demands | Low demands | Low demands | Low demands | High demands |
| Climate Status | Assumed Conditions | Same as 20th Century Observed | Same as 20th Century Observed | Between Hot and Dry and 20th Century Observed | Hot and Dry | Hot and Dry |
| | Supply Implications | ~ | ~ | - | - - | - - |
| Availability of Water Efficient Technology | Assumed Conditions | Similar to recent past | Similar to recent past. Poor economy results in less availability. | Technology advancements occur and are required | Technology advancements occur and are required | Similar to recent past |
| | M&SSI Demand Implications | Same as current | Same as current | Reduced demand | Reduced demand | Same as current |
| | Ag. Demand Implications | Same as current | Same as current | Efficiencies are implemented | Efficiencies are implemented | Same as current |
| Social / Environmental Values | Assumed Conditions | Same as current | Same as current | Increased awareness and willingness to conserve | Increased awareness and willingness to conserve | Same as current |
| | M&SSI Demand Implications | No change | No change | Reduced demand | Reduced demand | No change |
| | Ag. Demand Implications | No change | No change | Reduced demand | Reduced demand | No change |
| Regulatory Constraints | Assumed Conditions | Same as current | Same as current | Increased regulations on water development controls | Increased but well-defined regulatory climate | Reduced regulations |
| | M&SSI Demand Implications | No change | No change | Reduced demand | Reduced demand | Increased demand |
| | Ag. Demand Implications | No change | No change | Reduced demand | Reduced demand | Similar to recent past |

Table 2: CWP Planning Scenarios

| Scenario: | Narrative Description |
|---|---|
| **A: Business as Usual** | Recent trends continue into the future. Few unanticipated events occur. The economy goes through regular economic cycles but grows over time. By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas. Social values and regulations remain the same, but streamflows and water supplies show increased stress. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation of new water development slowly increases. Municipal water conservation efforts slowly increase. Oil-shale development continues to be researched as an option. Large portions of agricultural land around cities are developed by 2050. Transfer of water from agriculture to urban uses continues. Efforts to mitigate the effects of the transfers slowly increase. Agricultural economics continue to be viable, but agricultural water use continues to decline. The climate is similar to the observed conditions of the 20th century. |
| **B: Weak Economy** | The world's economy struggles, and the state's economy is slow to improve. Population growth is lower than currently projected, slowing the conversion of agricultural land to housing. The maintenance of infrastructure, including water facilities, becomes difficult to fund. Many sectors of the state's economy, including most water users and water dependent businesses, begin to struggle financially. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation decreases due to economic concerns. Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century. |
| C: Cooperative Growth | Environmental stewardship becomes the norm. Broad alliances form to provide for more integrated and efficient planning and development. Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and in mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development. Coloradans embrace water and energy conservation. New water-saving technologies emerge. Eco-tourism thrives. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits. Environmental regulations are more protective, and include efforts to re-operate water supply projects to reduce effects. Demand for more water-efficient foods reduces water use. There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting streamflows and supplies. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection. |
| D: Adaptive Innovation | A much warmer climate causes major environmental problems globally and locally. Social attitudes shift to a shared responsibility to address problems. Technological innovation becomes the dominant solution. Strong investments in research lead to breakthrough efficiencies in the use of natural resources, including water. Renewable and clean energy become dominant. Colorado is a research hub and has |

| Scenario: | Narrative Description |
|---|---|
| D: Adaptive Innovation (Continued) | a strong economy. The relatively cooler weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected. The warmer climate increases demand for irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand. The warmer climate reduces global food production increasing the market for local agriculture and food imports to Colorado. More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development. Higher water efficiency helps maintain streamflows, even as water supplies decline. The regulations are well defined and permitting outcomes are predictable and expedited. The environment declines and shifts to becoming habitat for warmer-weather species. Droughts and floods become more extreme. More compact urban development occurs through innovations in mass transit. |
| E: Hot Growth | A vibrant economy fuels population growth and development throughout the state. Regulations are relaxed in favor of flexibility to promote and pursue business development. A much warmer global climate brings more people to Colorado with its relatively cooler climate. Families prefer low-density housing and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed. A hotter climate decreases global food production. Worldwide demand for agricultural products rises, greatly increasing food prices. Hot and dry conditions lead to a decline in streamflows and water supplies. The environment degrades and shifts to becoming habitat for species adapted to warmer waters and climate. Droughts and floods become more extreme. Communities struggle unilaterally to provide services needed to accommodate the rapid business and population growth. Fossil fuel is the dominant energy source, and there is large production of oil shale, coal, natural gas, and oil in the state. |

# Section 3: SWSI Update Methodology

The following sections provide an overview of the water supply hydrologic modeling, M&SSI, agricultural, and environmental and recreation analysis methodologies, and how these methodologies fit into the context of the scenario planning approach.

Due to the new scenario planning approach, the SWSI update will result in a more scientifically rigorous and complex analysis. This approach will focus on hydrologic modeling to enable more detailed spatial analyses of impacts to water resources throughout the state. The modeling will also help provide more consistency in the representation of municipal and agricultural demand gaps. The result will be a wealth of data on impacts or "hydrologic gaps" at representative locations under each of the five planning scenarios. This approach will leverage the State's considerable investment in Colorado's Decision Support System (CDSS) tools and also incorporate other modeling tools as appropriate.

Due to data gaps, consistency issues, and roundtable feedback concerning planned projects (i.e. IPPs), the SWSI Update will not interpret or include IPPs in the modeling analysis, and consequently will not calculate an "infrastructure gap" similar to prior SWSI efforts. (The infrastructure gap was a simple basinwide and statewide calculation that subtracted the supply of planned projects from projected new demands.) Instead, the SWSI update will prepare BRTs for the forthcoming BIP updates, leaving the BRTs in control of how to evaluate projects in more detail in their forthcoming BIP updates.

# 3.1 SWSI Update Hydrologic Modeling Methodology Overview

Hydrologic modeling will be utilized to quantify supply versus demand gaps in the SWSI Update. For additional detail on water supply hydrologic modeling in the SWSI Update, please see the *SWSI Update - Water Supply Methodologies* TM. It is important to note that similar water allocation models do not currently exist in every basin. In basins where models do not currently exist, other models or analyses will be adapted to evaluate water availability and gaps. Hydrologic modeling, where available, is performed using the following general inputs:

1. An extended time series of "natural" stream flow data is developed for numerous locations throughout the watershed. "Natural" flow is the amount of flow in the river absent the effect of man, and serves as the foundation for the hydrologic models. This data can be developed by reviewing historical flow data at a stream gage and modifying that recorded flow by adjusting for human watershed operations that would have changed the flow at that particular location. This adjustment removes the effect of man-made diversions, return flows, storage operations, and transmountain diversions. For example, 1950 through 2015 natural stream flow may equal recorded gage flow at a given location for each month within that period plus known upstream diversions for the same period minus return flows, reservoir releases and known flow from transbasin diversions for the same period.
2. Structures, their associated water rights, and operations for current water uses in the basin are then included in the model. This information allows the hydrologic models to allocate water to these uses based on priority and simulate the stream according to Prior Appropriation. For example, a 2050 model run would include all current and constructed-to-date reservoirs and diversion structures, as well as operating rules associated with these structures. Operating rules specify when diversions can occur (based on available stream flows, demands at that location, and water rights conditions) and when reservoirs retain or release water.
3. Municipal, industrial, and agricultural diversion demands are incorporated into the hydrologic model. Demands reflect the amount of water that needs to be diverted at the headgate or pumped to meet the municipal and industrial uses or the crop irrigation water requirement. The models allocate water that is physically and legally available to the demands based on the priority of the water rights and operations. For example, a 2050 model run using a monthly time step would include 2050 demands for each modeled water use broken out into monthly demands. For the SWSI Update, municipal demands will represent average monthly demand projections for the year 2050, based on the 2050 population and other drivers for a given scenario, and the annual variations represent projected variability in 2050 outdoor uses under the given scenario but are not intended to represent how municipal demands 'grow into' the 2050 values between now and 2050.

Once the preceding inputs are determined, the hydrologic modeling process generally works as follows:

1. The modeler selects the natural stream flow data set to be used in the model simulation. This could be stream flow from recent recorded history (e.g. 1950 – 2015 flows) or a climate change adjusted natural stream flow data set representing potential future stream flow that may be different than past stream flow. Flows will vary by scenario for the SWSI Update.
2. The modeler selects a demand scenario (for example, 2050 Business As Usual scenario demands).
3. The modeler enters initial assumed water levels in all reservoirs within the model.
4. The model then performs calculations on a monthly timestep using the selected streamflows and demands while following all of the model operating rules. It is important to note that this type of model is essentially simulating how future demands would be met under historical hydrology that may occur again into the future, or climate-adjusted hydrology (when climate change scenarios are evaluated).

General modeling outputs include:

1. Streamflow at each timestep for each streamflow node.
2. Water contents in each reservoir for each timestep.
3. Unappropriated water at each diversion node (conditions where physically and legally available flow are greater than demands at that node and water reserved at that node for downstream nodes)
4. Water gaps at each diversion node (conditions where physically and legally available flow are less than demands at that node, and water is reserved to meet downstream senior users)

Benefits of this hydrologic modeling approach include the fact that gaps calculated using extended period hydrologic modeling methods avoid the potential that average demands minus average supplies might not capture the magnitude of extreme gaps that can occur in select phases of a hydrologic period[2]. Gaps calculated using extended period hydrologic modeling methods provide perspective on the frequency and duration of gaps, and this knowledge may lead to the selection of different types of IPPs to resolve gaps. Additionally, hydrologic models calculate future water flow and gaps at specific locations in the river basins. This information provides greater spatial insight into the locations of future gaps and is useful in comparing potential future flows in environmental and recreation focus areas.

## 3.2 SWSI Update M&SSI Demand Quantification Method Overview

2050 population projections will be developed for all five future planning scenarios. The Business as Usual projections are based on current Colorado State Demographer Office (SDO) economic modeling and consider the land use assumptions, economic conditions, and social drivers that qualify the general population growth for the state and the growth in each county throughout the state. Due to complexities associated with adjusting the SDO population model, statistical methods will be used to develop state wide populations for the other scenarios. Spatial distributions of the state-wide projections will be further developed by scenario at the county level in accordance with the scenario narratives, resulting in five unique population sets that align with the five planning scenarios. By considering this full range of population drivers, the analysis will not just test different general growth rates but also the varying impacts of growth occurring in different regions of Colorado. For more detail, please see the *SWSI Update - Methodology for Developing SWSI Population Scenarios* TM.

2050 municipal demands will be calculated for each county by multiplying 2050 populations by 2050 projected gallons per capita per day (gpcd) demand rates for that county. Unique 2050 gpcd rates for each geographic area will be estimated for each future planning scenario by considering the land use, economic, climate, regulatory and technology, and social conditions defined by each scenario narrative. SSI demands will be represented using data provided in SWSI 2010. Where available, the SWSI 2010 low, medium, or high values will be assigned to a scenario to reflect scenario drivers.

A summary of the key drivers of uncertainty associated with M&SSI demands and how the M&SSI demand parameters will be adjusted to calculate demands for each scenario is shown in Table 2. It is important to note that some scenarios outlined in the following table assume that inherent conservation occurs as part of the defined future condition. When this is the case, Basin Roundtables must consider this initial conservation benefit and not select IPPs that would result in a double count of the same conservation mechanism. Also, Basin Roundtables should consider if selected IPPs are consistent with the scenario definition. For example, if the scenario narrative indicates conditions being evaluated include a weak future economy with limited technology advancements, IPPs that required a strong economy and technology advancements should not be included as IPPs for that scenario.

[2] The municipal demands represent average values for the year 2050, with the monthly and annual variations representing variability around the 2050 conditions. In an extended drought, municipalities may implement drought restrictions which will reduce the municipal demands. This type of drought management activity and associated effects is not included in this modeling effort.

Table 3: M&SSI Demands Potential Parameter Adjustments for Each SWSI Scenario

| Key Driver | Water Demand Model Parameter | | M&SSI Parameter Adjustment from Historical by Scenario | | | | |
|---|---|---|---|---|---|---|---|
| | | | Scenario A Business as Usual | Scenario B Weak Economy | Scenario C Cooperative Growth | Scenario D Adaptive Innovation | Scenario E Hot Growth |
| Land Use & Associated Population Growth | Population | *Narrative Description* | Per SDO Office Forecast | Lower population growth throughout the state than under the SDO forecast. Growth reduced most in basins that have historically experienced the largest "busts" | Overall urban and rural growth per SDO forecast, but more population growth in urban centers and mountain resort areas | More population growth than forecasted by SDO with greatest growth in urban areas | More population growth than forecasted by SDO with growth in both urban and suburban areas |
| | | *Visual Representation* | ~ | - | ~ | + | + |
| | | *Quantification (if applicable)* | No adjustment from SDO forecast | Use "Low" (90% exceedance probability) forecast | Use SDO forecast, with mountain resort community growth adjust up by 20%, and urban center population adjusted up by 10% | Use "High" (10% exceedance probability) forecast, maintaining high unconstrained growth forecasts for urban centers | Use "High" (10% exceedance probability) forecast |
| Economic Growth[1] | Indoor and Outdoor gpcd | *Narrative Description* | Economic conditions have similar to historic impact on water use | Low salaries limit water purchases | Economic conditions have similar to historic impact on water use | Economic conditions have similar to historic impact on water use | Increased oil and gas production increases water use |
| | | *Visual Representation* | ~ | - | ~ | ~ | ++ |
| | | *Quantification (if applicable)* | 42.4 gpcd for Residential Indoor Future, -3% economic growth adjustment for non-residential indoor, 0% adjustment for outdoor, current water loss | 42.4 gpcd for Residential Indoor Future, -6% economic growth adjustment for non-residential indoor, 0% adjustment for outdoor, 13% water loss | 36.4 gpcd for Residential Indoor Future, -3% economic growth adjustment for non-residential indoor, -20% adjustment for outdoor, 8% water loss | 36.4 gpcd for Residential Indoor Future, -3% economic growth adjustment for non-residential indoor, -20% adjustment for outdoor, 8% water loss | 40.9 gpcd for Residential Indoor Future, -3% economic growth adjustment for non-residential indoor, 0% adjustment for outdoor, |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | current water loss |
| Climate Conditions | Outdoor gpcd | *Narrative Description* | Water use not significantly impact by climate change | Water use not significantly impact by climate change | Moderate warming results in slight increase of outdoor ET | Significant warming results in increased outdoor ET | Significant warming results in increased outdoor ET |
| | | *Visual Representation* | ~ | ~ | + | ++ | ++ |
| | | *Quantification (if applicable)* | Current | Current | % adjustment to outdoor gpcd based on relative difference between Current and In-Between climate conditions | % adjustment to outdoor gpcd based on relative difference between Current and Hot-and-Dry climate conditions | % adjustment to outdoor gpcd based on relative difference between Current and Hot-and-Dry climate conditions |
| Regulations & Technology Change[1] | Indoor and Outdoor gpcd | *Narrative Description* | Regulations / technology does not change historic water use | Poor economy results in reduced maintenance & increased leakage | Water saving technology advancements occur and are required | Water saving technology advancements occur and are required | Regulations are relaxed in favor of business |
| | | *Visual Representation* | ~ | ~ | - - | - - | + |
| | | *Quantification (if applicable)* | 0% adjustment for non-residential indoor | 0% adjustment for non-residential indoor | -6% adjustment for non-residential indoor | -7% adjustment for non-residential indoor | -3% adjustment for non-residential indoor |
| Social Values Changes[1] | Indoor and Outdoor gpcd | *Narrative Description* | Social values do not change historic water use behaviors | Social values do not change historic water use behaviors | Increased conservation behaviors | Increased conservation behaviors | Social values do not change historic water use behaviors |
| | | *Visual Representation* | ~ | ~ | - - | - - | ~ |
| | | *Quantification (if applicable)* | -3% adjustment for non-residential indoor | 0% adjustment for non-residential indoor | -6% adjustment for non-residential indoor | -6% adjustment for non-residential indoor | -3% adjustment for non-residential indoor |

1. Economic growth, regulations & technology, and social values parameters may not be explicitly quantified and may change due to upcoming further analysis and TAG input. Scenario percent adjustment factors for regulations & technology, and social values changes shown in this table are example adjustments and may be aggregated for the M&SSI demand analysis. GPCD values are provided for illustrative purposes, and will be updated as the methodology is applied.

For more detail on the development and implementation of these parameters and adjustment, please see the *SWSI Update - Municipal and Self-Supplied Industrial Demand Methodologies* TM for a detailed description of demand quantification methods used for each scenario.

## 3.3 SWSI Update Agriculture Demand Quantification Method Overview

Agricultural “demands” are defined as water predominantly used for irrigation of crops. Additional smaller components of the agricultural demand included water use associated with livestock production, stock pond evaporation, and losses incidental to delivering irrigation water. Agricultural “demands” are defined in the SWSI Update as diversion demands necessary to meet the full irrigation water requirement - not historical diversions or the Irrigation Water Requirement that was used in the previous SWSI 2010 analysis.

For the SWSI Update, 2050 irrigated acreage by crop type will be developed for all five future planning scenarios. The total irrigated acreage will consider relevant land use assumptions and how future population growth may result in conversion of some agricultural lands to urban/suburban lands. The StateCU consumptive use model will be used to calculate crop consumptive use for the assumed acres and crop type. Baseline consumptive use estimates will be adjusted for the select scenarios that assume warmer climate conditions. Specifically, there is a climate adjustment factor for the “Hot & Dry” climate condition and “In-Between” climate condition. These climate conditions are described in more detail in Section 3.4.

The agricultural diversion demand is then calculated by dividing the crop consumptive use by an irrigation system efficiency factor. Note that the irrigation system efficiency varies based on hydrologic conditions and the unique conditions of each system. Therefore, system efficiency factors will be developed for average, wet, and dry hydrologic years for each agricultural demand node as described in detail in the *SWSI Update - Agricultural Demand Methodologies* TM.

A summary of the key drivers of uncertainty associated with agricultural demands and how the agricultural demand parameters will be adjusted to calculate demands for each scenario is shown in Table 3.

Table 4: Agricultural Demands Potential Parameter Adjustments for Each SWSI Scenario

| Key Driver | Water Demand Model Parameter | | Agricultural Parameter Adjustment from Historical by Scenarios | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Scenario A Business as Usual** | **Scenario B Weak Economy** | **Scenario C Cooperative Growth** | **Scenario D Adaptive Innovation** | **Scenario E Hot Growth** |
| Land Use Changes | Acres of Crops | *Narrative Description* | Most Ag. land around cities are converted to housing | Lesser Ag. land around cities are converted to housing | Lesser Ag. land around cities are converted to housing | Lesser Ag. land around cities are converted to housing | More Ag. land near cities and in rural areas is converted to housing |
| | | *Visual Representation* | - - | - | - | - | - - - |
| | | *Quantification (if applicable)* | Will be developed in upcoming technical analyses | Will be developed in upcoming technical analyses | Will be developed in upcoming technical analyses | Will be developed in upcoming technical analyses | Will be developed in upcoming technical analyses |
| Climate Conditions | Crop Consumptive Use | *Narrative Description* | Similar to recent past | Similar to recent past | Moderate warming | Much warmer | Much warmer |
| | | *Visual Representation* | ~ | ~ | + | ++ | ++ |
| | | *Quantification (if applicable)* | % change in IWR by Water District for Current climate factor (0% change) | % change in IWR by Water District for Current climate factor (0% change) | % change in IWR by Water District for In Between climate factor (avg. annual increase of 10-27%) | % chance in IWR by Water District for Hot and Dry climate factor (avg. annual increase of 16-38%) | % chance in IWR by Water District for Hot and Dry climate factor (avg. annual increase of 16-38%) |
| Technology Changes | Irrigation Efficiency[1] | *Narrative Description* | Similar to recent past | Similar to recent past | New technologies increase efficiency | New technologies increase efficiency | Similar to recent past |
| | | *Visual Representation* | ~ | ~ | + | + | ~ |
| Social Values Changes | Crop Types[1] | *Narrative Description* | Similar to recent past | Similar to recent past | Demand for more water efficient foods changes some crop acreage from alfalfa to soybeans | Demand for locally grown foods converts some crops from alfalfa to soybeans and other crops | Similar to recent past |
| | | *Visual Representation* | ~ | ~ | - | - | ~ |

1. *These parameters may not be explicitly modeled and instead may be evaluated in hypothetical case studies*

For more detail on the development and implementation of these parameters and adjustment, please see the *SWSI Update - Agricultural Demand Methodologies* TM for a detailed description of demand quantification methods used for each scenario.

## 3.4 Future Surface Water Flows and Sustainable Groundwater Pumping for SWSI Update

To incorporate future climate variability into the SWSI Update, three future natural stream flow data sets will be utilized for the hydrologic modeling analysis, summarized below:

1. **20$^{th}$ Century Observed (aka Current):** This contains the streams flows observed generally between 1950 and 2015.
2. **Hot & Dry:** Was selected by the Interbasin Compact Committee (IBCC) based on the recently completed CWCB studies supporting the Colorado Climate Plan (CCP). This climate scenario was selected by reviewing a wide set of 2050 climate analyses and selecting a condition generally aligning with the 25$^{th}$ percentile for climate adjusted natural flows.
3. **In-Between:** Was selected by the IBCC as a condition for in-between the Hot & Dry and 20$^{th}$ Century Observed and generally aligns with the 50$^{th}$ percentile for climate adjusted natural flows.

Sustainable groundwater pumping will be tabulated for each basin by referencing recent sustainable yield studies or referencing basin adopted targets for reduced pumping.

## 3.5 Hydrologic Modeling Inputs for SWSI Update Scenarios

Baseline hydrologic modeling will be performed by basin for each of the five defined 2050 future planning scenarios. A summary of M&SSI demand, Agricultural demand, and hydrologic modeling inputs for each scenario are shown in Tables 4 through 8.

Table 5: SWSI Update Scenario A Hydrologic Modeling Inputs

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario A: Business as Usual |
|---|---|---|---|---|
| M&SSI Demands | By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas. Municipal water conservation efforts slowly increase. | Land Use & Associated Population Growth | Population | ~<br>Per SDO Office Forecast |
| | The economy goes through regular economic cycles but grows over time. | Economic Growth | Indoor and Outdoor gpcd | ~<br>Economic conditions have similar to historic impact on water use |
| | The climate is similar to the observed conditions of the 20th century. Municipal water conservation efforts slowly increase. | Climate Conditions | Outdoor gpcd | ~<br>Water use not significantly impact by climate change |
| | Social values and regulations remain the same. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. | Regulations & Technology Change | Indoor and Outdoor gpcd | ~<br>Regulations / technology does not change historic water use |
| | Social values and regulations remain the same. Willingness to pay for social and environmental mitigation of new water development slowly increases. | Social Values Changes | Indoor and Outdoor gpcd | ~<br>Social values do not change historic water use behaviors |
| Agricultural Demands | Transfer of water from agriculture to urban uses continues. Efforts to mitigate the effects of the transfers slowly increase. Large portions of agricultural land around cities are developed by 2050. | Land Use Changes | Acres of Crops | - -<br>Most Ag. land around cities are converted to housing |
| | The climate is similar to the observed conditions of the 20th century. | Climate Conditions | Crop Consumptive Use | ~<br>Similar to recent past |
| | Agricultural economics continue to be viable, but agricultural water use continues to decline. | Technology Changes | Irrigation Efficiency[1] | ~<br>Similar to recent past |
| | Social values and regulations remain the same. | Social Values Changes | Crop Types[1] | ~<br>Similar to recent past |
| Hydrologic Modeling Inputs | The climate is similar to the observed conditions of the 20th century. | - | Stream Flows | $20^{th}$ century observed |

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario A: Business as Usual |
|---|---|---|---|---|
| | - | - | Demands | 2050 Scenario A Demands |

1. These parameters may not be explicitly modeled and instead may be evaluated in hypothetical case studies

Table 6: SWSI Update Scenario B Hydrologic Modeling Inputs

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario B: Weak Economy |
|---|---|---|---|---|
| M&SSI Demands | Population growth is lower than currently projected, slowing the conversion of agricultural land to housing. | Land Use & Associated Population Growth | Population | -<br>Rural areas have less population decline than SDO forecast & urban areas have less growth than SDO forecast |
| | The world's economy struggles, and the state's economy is slow to improve. Many sectors of the state's economy, including most water users and water dependent businesses, begin to struggle financially. | Economic Growth | Indoor and Outdoor gpcd | -<br>Poor economy limits water purchases |
| | Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century. | Climate Conditions | Outdoor gpcd | ~<br>Water use not significantly impact by climate change |
| | Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. The maintenance of infrastructure, including water facilities, becomes difficult to fund. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. | Regulations & Technology Change | Indoor and Outdoor gpcd | ~<br>Poor economy results in reduced maintenance & increased leakage |
| | There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. | Social Values Changes | Indoor and Outdoor gpcd | ~<br>Social values do not change historic water use behaviors |
| Agricultural Demands | Population growth is lower than currently projected, slowing the conversion of agricultural land to housing. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. | Land Use Changes | Acres of Crops | -<br>Lesser Ag. land around cities are converted to housing |
| | Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century. | Climate Conditions | Crop Consumptive Use | ~<br>Similar to recent past |
| | There is little change in social values, levels | Technology Changes | Irrigation Efficiency[1] | ~ |

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario B: Weak Economy |
|---|---|---|---|---|
| | of water conservation, urban land use patterns, and environmental regulations. | | | Similar to recent past |
| | There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. | Social Values Changes | Crop Types[1] | ~ |
| | | | | Similar to recent past |
| Hydrologic Modeling Inputs | Greenhouse gas emissions do not grow as much as currently projected and the climate is similar to the observed conditions of the 20th century. | - | Stream Flows | $20^{th}$ century observed |
| | - | - | Demands | 2050 Scenario B Demands |

. These parameters may not be explicitly modeled and instead may be evaluated in hypothetical case studies

Table 7: SWSI Update Scenario C Hydrologic Modeling Inputs

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario C: Cooperative Growth |
|---|---|---|---|---|
| M&SSI Demands | Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and in mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development. | Land Use & Associated Population Growth | Population | ~<br>Overall urban and rural growth per SDO forecast, but more population in urban areas than suburban areas. |
| M&SSI Demands | Broad alliances form to provide for more integrated and efficient planning and development. Eco-tourism thrives. | Economic Growth | Indoor and Outdoor gpcd | ~<br>Economic conditions have similar to historic impact on water use |
| M&SSI Demands | There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting streamflows and supplies. | Climate Conditions | Outdoor gpcd | +<br>Moderate warming results in slight increase of outdoor ET |
| M&SSI Demands | Coloradans embrace water and energy conservation. New water-saving technologies emerge. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits. Environmental regulations are more protective, and include efforts to re-operate water supply projects to reduce effects. | Regulations & Technology Change | Indoor and Outdoor gpcd | - -<br>Water saving technology advancements occur and are required |
| M&SSI Demands | Environmental stewardship becomes the norm. Coloradans embrace water and energy conservation. Demand for more water-efficient foods reduces water use. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection. | Social Values Changes | Indoor and Outdoor gpcd | - -<br>Increased conservation behaviors |
| Agricultural Demands | Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and in mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development. | Land Use Changes | Acres of Crops | -<br>Lesser Ag. land around cities are converted to housing |
| Agricultural Demands | There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting streamflows and supplies. | Climate Conditions | Crop Consumptive Use | +<br>Moderate warming |
| Agricultural Demands | Coloradans embrace water and energy conservation. New water-saving technologies emerge. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits. | Technology Changes | Irrigation Efficiency[1] | +<br>New technologies increase efficiency |

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario C: Cooperative Growth |
|---|---|---|---|---|
| | Environmental stewardship becomes the norm. Coloradans embrace water and energy conservation. Demand for more water-efficient foods reduces water use. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection. | Social Values Changes | Crop Types[1] | - |
| | | | | Demand for more water efficient foods changes some crop acreage from alfalfa to soybeans |
| Hydrologic Modeling Inputs | There is a moderate warming of the climate, which results in increased water use in all sectors, in turn affecting streamflows and supplies. | - | Stream Flows | In-between 20th century observed and hot and dry |
| | | - | Demands | 2050 Scenario C Demands |

1. These parameters may not be explicitly modeled and instead may be evaluated in hypothetical case studies

Table 8: SWSI Update Scenario D Hydrologic Modeling Inputs

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario D: Adaptive Innovation |
|---|---|---|---|---|
| M&SSI Demands | The relatively cooler weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected. More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development. More compact urban development occurs through innovations in mass transit. | Land Use & Associated Population Growth | Population | +<br>More population growth than forecasted by SDO with greatest growth in urban areas |
| | Renewable and clean energy become dominant. Colorado is a research hub and has a strong economy. The warmer climate reduces global food production increasing the market for local agriculture and food imports to Colorado | Economic Growth | Indoor and Outdoor gpcd | ~<br>Economic conditions have similar to historic impact on water use |
| | A much warmer climate causes major environmental problems globally and locally. | Climate Conditions | Outdoor gpcd | ++<br>Significant warming results in increased outdoor ET |
| | Technological innovation becomes the dominant solution. Strong investments in research lead to breakthrough efficiencies in the use of natural resources, including water. The warmer climate increases demand for irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand. The regulations are well defined and permitting outcomes are predictable and expedited. | Regulations & Technology Change | Indoor and Outdoor gpcd | - -<br>Water saving technology advancements occur and are required |
| | Social attitudes shift to a shared responsibility to address problems | Social Values Changes | Indoor and Outdoor gpcd | - -<br>Increased conservation behaviors |
| Agricultural Demands | More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development. | Land Use Changes | Acres of Crops | -<br>Lesser Ag. land around cities are converted to housing |
| | A much warmer climate causes major environmental problems globally and locally. | Climate Conditions | Crop Consumptive Use | ++<br>Much Warmer |
| | The warmer climate increases demand for | Technology | Irrigation Efficiency[1] | + |

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario D: Adaptive Innovation |
|---|---|---|---|---|
| | irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand. | Changes | | New technologies increase efficiency |
| | The warmer climate reduces global food production increasing the market for local agriculture and food imports to Colorado. More food is bought locally, increasing local food prices and reducing the loss of agricultural land to urban development. | Social Values Changes | Crop Types[1] | -<br>Demand for locally grown foods converts some crops from alfalfa to soybeans and other crops |
| Hydrologic Modeling Inputs | A much warmer climate causes major environmental problems globally and locally. Droughts and floods become more extreme. | - | Stream Flows | Hot and dry |
| | | - | Demands | 2050 Scenario D Demands |

1. These parameters may not be explicitly modeled and instead may be evaluated in hypothetical case studies

Table 9: SWSI Update Scenario E Hydrologic Modeling Inputs

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario E: Hot Growth |
|---|---|---|---|---|
| M&SI Demands | A vibrant economy fuels population growth and development throughout the state. Families prefer low-density housing and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed. A much warmer global climate brings more people to Colorado with its relatively cooler climate. | Land Use & Associated Population Growth | Population | + <br> More population growth than forecasted by SDO with growth in both urban and suburban areas |
| | A vibrant economy fuels population growth and development throughout the state. Worldwide demand for agricultural products rises, greatly increasing food prices. Fossil fuel is the dominant energy source, and there is large production of oil shale, coal, natural gas, and oil in the state. | Economic Growth | Indoor and Outdoor gpcd | ++ <br> Increased oil and gas production increases water use |
| | Hot and dry conditions lead to a decline in streamflows and water supplies. A much warmer global climate brings more people to Colorado with its relatively cooler climate. | Climate Conditions | Outdoor gpcd | ++ <br> Significant warming results in increased outdoor ET |
| | Regulations are relaxed in favor of flexibility to promote and pursue business development. | Regulations & Technology Change | Indoor and Outdoor gpcd | + <br> Regulations are relaxed in favor of business |
| | Regulations are relaxed in favor of flexibility to promote and pursue business development. | Social Values Changes | Indoor and Outdoor gpcd | ~ <br> Social values do not |

| | Relevant Scenario Narrative Language | Key Driver | Water Demand Model Parameter | Scenario E: Hot Growth |
|---|---|---|---|---|
| | | | | change historic water use behaviors |
| Agricultural Demands | Agricultural and other open lands are rapidly developed. | Land Use Changes | Acres of Crops | - - - |
| | | | | More Ag. land near cities and in rural areas is converted to housing |
| | Hot and dry conditions lead to a decline in streamflows and water supplies. A much warmer global climate brings more people to Colorado with its relatively cooler climate. A hotter climate decreases global food production. Worldwide demand for agricultural products rises, greatly increasing food prices. | Climate Conditions | Crop Consumptive Use | ++ |
| | | | | Much Warmer |
| | Regulations are relaxed in favor of flexibility to promote and pursue business development. | Technology Changes | Irrigation Efficiency[1] | ~ |
| | | | | Similar to recent past |
| | Agricultural and other open lands are rapidly developed. | Social Values Changes | Crop Types[1] | ~ |
| | | | | Similar to recent past |
| Hydrologic Modeling Inputs | Hot and dry conditions lead to a decline in streamflows and water supplies. Droughts and floods become more extreme. | - | Stream Flows | Hot and dry |
| | | - | Demands | 2050 Scenario E Demands |

1. These parameters may not be explicitly modeled and instead may be evaluated in hypothetical case studies

Baseline modeling incorporates scenario-defined 2050 demands and 2050 streamflows with current infrastructure and operating rules. These model runs will show streamflow conditions, unappropriated water availability, and water gaps without the implementation of future IPPs. The updated range of gaps for each basin will be provided to the basins and will be a starting point for subsequent BRT-directed Basin Implementation Plan updates.

## 3.6 Hydrologic Modeling Outputs for SWSI Update

Using the streamflow and demand data sets described in the previous sections, a time series of data will be available for all of the future demand scenarios. Modeling results will be developed at major reservoirs and environmentally sensitive reaches, or representative locations where future demand may be expected. Modeling outputs will vary based on model availability and/or hydrologic analyses performed in each basin. Table 9 shows key outputs that will be used to summarize the results for each modeled scenario.

Table 10: SWSI Update Hydrologic Modeling Outputs

| Parameter | Time Series Plot | Min AF/Month | Max AF/Month | Average Annual Volume AF/Year | | |
|---|---|---|---|---|---|---|
| | | | | All Wet Years | All Normal Years | All Dry Years |
| Streamflow | x | x | x | x | x | x |
| Reservoir Contents | x | NA | NA | NA | NA | NA |
| Unappropriated Water | x | NA | NA | x | x | x |
| Gaps | x | NA | NA | x | x | x |

## 3.7 Environmental & Recreation Flows Assessment Methodology Overview

As described in more detail in the *SWSI Update - Environment and Recreation Methodologies* TM, an environmental and recreation flow tool will be developed that will accept stream flow time series data for each of the evaluated scenarios and perform a comparative analysis to varying stream flow conditions. More specifically the flow tool will accomplish the following:

- Allow users to produce comparison graphs of flow outputs across the five future planning scenarios.
- Demonstrate projected changes in monthly flow regimes at indicator locations under different planning horizons.
- Allow for a spatial linkage between locations of environmental and recreation flow IPPs and flow conditions in those reaches.
- Serve as a key tool for decision making in the next round of BIPs.
- Serve as a key tool for providing guidance during Stream Management Plan development.

# Section 4: Sign Post Indicators (Post-SWSI Update)

Although development of sign post indicators is not a part of the SWSI Update analysis, indicators could be developed in future post-SWSI Update efforts to assist CWCB and the Basin Roundtables in monitoring the critical drivers of water supply and water use in the future, and gain a general understanding of how future conditions are trending towards or away from any of the defined scenario conditions. This information could be useful to CWCB and the Basin Roundtables in developing appropriate water supply/action portfolios, and in understanding which supply and demand conditions are becoming reality over time. Previously compiled data, if available, could be retroactively evaluated as well to extend the timeframe of indicator monitoring. This knowledge can help benchmark the starting point for future SWSI updates, assist in future planning and decision making efforts, and provide information on deciding when, why, and where to take certain future water supply actions.

Some example sign post indicators may include:

- Comparing population growth and location of that growth to assumed growth defined in the scenario narratives.
- Comparing municipal gpcd water usage as documented in HB 1051 water usage data submittals to stated water usage trends defined in the scenario narratives.
- Comparing crop acreage, crop types, and irrigation diversions to assumed agricultural conditions defined in the scenario narratives.
- Comparing precipitation events, natural stream flows, and temperature conditions to the recorded 20th Century conditions.
- Compare biological sign-post indicators, and build on ongoing biological indicator work by others
- Comparing stream flows in environmental and recreation focus areas to recorded 20th Century Conditions and compare to assumed conditions defined in the scenario narratives.

# References

Colorado Water Conservation Board, Statewide Water Supply Initiative, 2010.

Colorado Water Conservation Board, Colorado's Water Plan, 2015.